A Unified Architecture for Cognition and Motor Control Based on Neuroanatomy, Psychophysical Experiments, and Cognitive Behaviors

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Overview: A Brain-Emulating Cognition and Control Architecture (BECCA) is presented. It is consistent with the hypothesized functions of pervasive intra-cortical and cortico-subcortical neural circuits. It is able to reproduce many salient aspects of human voluntary movement and motor learning. It also provides plausible mechanisms for many phenomena described in cognitive psychology, including perception and mental modeling. Both "inputs" (afferent channels) and "outputs" (efferent channels) are treated as neural signals; they are all binary (either on or off) and there is no meaning, information, or tag associated with any of them. Although BECCA initially has no internal models, it learns complex interrelations between outputs and inputs through which it bootstraps a model of the system it is controlling and the outside world. BECCA uses two key algorithms to accomplish this: S-Learning and Context-Based Similarity (CBS).

S-Learning: S-Learning is an experience-based learning approach in which sequences of states (the set of inputs and outputs at discrete time intervals) are recorded directly into a library. During goal-directed behavior, the library is searched for sequences that begin at the current state and end at a goal state. These successful sequences are replicated as nearly as possible in order to achieve the goal again. S-Learning's lack of an a priori model of the system allows it to learn hard non-linear, time-delayed, and stochastically varying dynamics. S-Learning is demonstrated controlling a simulated 7 degree of freedom robotics arm.

Context-Based Similarity: CBS uses the library created by the S-Learning algorithm to form abstract concepts. CBS assumes that states are likely to be similar if they are preceded and followed by the same state prefix and state postfix. For instance, given two sequence of three states, A-B-C and A-Z-C, the states B and Z are assumed to be related. Taken over a large library, CBS can form an extensive set of abstract concepts based only on raw observations. These concepts can be then be used as the inputs to another instance of S-Learning and CBS which in turn create higher-level concepts. This hierarchical organization can be extended to as many levels as desired. CBS is shown generating synonym groups from raw English texts without the aid of dictionaries, thesauruses, text tagging, or a grammar model.

Biological Relevance: The discrete nature of human motor commands (Woodworth 1899) and sensory experiences (VanRullen and Koch 2003) are assumptions upon which BECCA is based. Thalamocortical structures suggest that processing is conducted in periodic steps and stored sequentially. (Rodriguez, Whitson, and Granger 2004) The storage transition of sequential patterns that appears to occur between the hippocampus, parahippocampus, and cortex provides the scaffolding required to store complex sequences in cortico-cortical networks. (Eichenbaum et al. 1999) Cerebellar-cortical-basal-ganglionic loops are likely candidates for classifying and selecting between multiple competing sequences. (Houk 2005) BECCA displays several attributes of human motor behavior, including learning through exploration and task transfer.

Discussion: BECCA forms a world model and conceptual representations directly from its experiences. This is in strong contrast with cognitive models in which conceptual domains are pre-determined by the operator. BECCA's approach removes the limitations inherent in any fixed-domain cognitive model and allows for a continual increase in the sophistication of physical behaviors and cognitive representations.

References

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